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The Study of Distributive Parameter Systems for Flight Control

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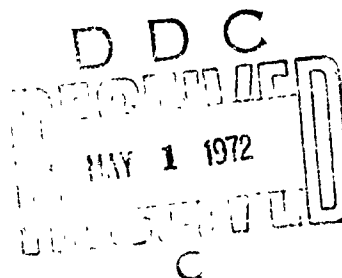
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University of Minnesota

Center for Control Sciences

Institute of Technology

Minneapolis, Minnesota 55455

Principal Investigator: E. B. Lee

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13. ABSTRACT

The research conducted during the last year has been primarily directed toward the development of new controller synthesis techniques for large modern Air Force aircraft. Control and modeling of systems with distributive parameters and time delays have been considered. The goal has been to evolve techniques which can be readily used in the design of controllers to reduce structural loading during wind gusts and in the design of controllers which can be used in configuring the vehicle to reduce appendage size and weight while maintaining satisfactory aircraft handling characteristics. An eventual goal is to have techniques of synthesis which take account of control capabilities during the original configuring of the behicle, that is, to enable design of the control system in parallel with the structure and propulsion systems.

Abstract of Research Conducted

The research conducted during the last year has been primarily directed toward the development of new controller synthesis techniques for large modern Air Force aircraft. Control and modeling of systems with distributive parameters and time delays have been considered. The goal has been to evolve techniques which can be readily used in the design of controllers to reduce structural loading during wind gusts and in the design of controllers which can be used in configuring the vehicle to reduce appendage size and weight while maintaining satisfactory aircraft handling characteristics. An eventual goal is to have techniques of synthesis which take account of control capabilities during the original configuring of the vehicle, that is, to enable design of the control system in parallel with the structure and propulsion systems.

Accomplishments during the last year include:

1) Completion of the quadratic theory of optimization for linear system with time delays in the state and control action.

2) Generalization of the theory of controllability and observability to dynamical systems having state variable as a point in an infinite dimensional space.

3) Evaluation of various pattern recognition schemes for identifying faults in physical systems (electric networks).

4) Completion of work on techniques for simulating system with time delays using a hybrid computer and an evaluation of various schemes for identifying parameters of time delay systems.

Further discussion of these studies appear in the next section of this report. At the present time the work is continuing on the theory of control configured vehicles and combined structural design-control system design problem. The development of the theory of controllability, stability, and observability for infinite dimensional dynamical systems is being continued.

Discussion of research conducted

The research has centered on the development of techniques for controller synthesis when the controlled system has many degrees of freedom (including distributive parameters and time delays). Theoretical topics which have promise of providing controller synthesis procedures have been under continual investigation.

In particular the theory of "quadratic control" for systems with time delays and distributive parameters and a system theory for generalized dynamical systems have been pursued.

The research to extend the quadratic theory to the more general model with time delays and distributive parameters was done by H. Koivo.[3] He established that the Fredholm resolvent theory is a versatile tool for solving quadratic control problems with time delay constraints. Previous work of Schumitzky had shown that certain matrix Riccati equations are equivalent to Fredholm resolvents. Koivo was able to extend this equivalence to generalized Riccati equations that arise in the quadratic theory for time delay systems, and thereby established a link between the known Carathéodory theory of feedback controllers and the maximum principle theory. He also studied the problem of synthesis of feedback controllers when retardation occurs in both the state and control variables (the delay in the control action happens naturally in practically all feedback control designs). Using the Fredholm resolvent theory and the maximum principle for such delayed action problems Koivo and Lee[6] were able to complete the theory of feedback control for the delayed action systems. The quadratic problem for distributive systems was treated in a similar manner.[3]

Roberto Triggiani (in his Ph.D. thesis project) has begun investigating system properties for systems modeled by abstract differential equations, where the system state is a point in a separable real infinite dimensional Banach space. This model includes classes of distributive parameter systems expressed by integro-differential equations and infinite systems of linear differential equations. His main concern has been to extend the controllability theory (and also stability and observability theory) of finite dimensional systems to this more general type. He introduced the concept of approximate controllability and established a criterion for testing the approximate controllability (which is similar to the test in the finite dimensional case) using the Hahn-Banach theorem.

He has also introduced a concept of asymptotic null controllability, but in contrast to the finite dimensional case such controllability does not in general imply the possibility of selecting a real bounded linear feedback functional such that the operator of the "closed loop" system has its spectrum in the left half plane. He is able to find subclasses which have this property. Triggiani has also been able to show that approximate controllability admits a dual version for observability for the abstract system.

The thesis work of Donald Gustafson[2] was concerned with the simulation of systems with time delays and evaluation of various algorithms for identifying parameters of time delay systems. A waveform reconstruction method was devised to minimize the effects of zero-order hold circuitry present in normal sampled-data systems and to compensate for time quantization errors. The various software routines necessary for the simulation and identification are indicated in the thesis.

Some effort was devoted to vehicle control problems of various transportation systems. Kris Burhardt[1] considered a traffic network consisting of many oversaturated intersections. The problem he considered was that of formulating realistic goals for the system and the optimization of the switching cycle of the lights used to control the flow in the network. Functional analysis and a maximum principle were satisfactorily applied to this problem. David Scharmack (in his Ph.D. thesis project) is considering the empty vehicle shuttling problem for various small vehicle transportation system. A stochastic model for the system has been developed which can be used in the design of stations in the system. In particular he is able to predict customer waiting times and rules for shuttling vehicles within the system.

Work is continuing (Thesis project of Robert Stover) to develop better techniques for detection of faults in electronic circuits. At present various pattern recognition schemes are

being modified and tested to determine their applicability to the fault detection problem, (the hybrid computer is being used in the training phase).

The control of a large flexible spinning space station is being investigated by S. Hummel in his Ph.D. Thesis research. Basically he is trying to determine the control logic to be used when men and equipment move in predetermined paths in the station.

Also the theory of optimal control from the set of attainability point of view was extended to certain linear periodic systems. The results of this study are reported in the paper of Lee and Spyker.[7]

Other Activities

Dr. E.B. Lee took part in the IFAC conference on Distributed Systems held in Banff, Canada during June, the all Union Conference on Control Problems held in Moscow during September and an International Conference on Systems Theory held on the Sanibel Island during January. In addition he visited the Technical University of Warsaw for one week in October and gave a seminar talk at the Institute for Information Sciences and Automation of the Czechoslovakian Academy of Science in Prague. He also took part in the final oral briefing on the control configured vehicle (CCV) advanced study contracts of Honeywell-

Lockheed, Boeing, Cornell and McDonnell held at the Air Force
Flight Dynamics Laboratory in Dayton during February.

As Associate director of the Center for Control Sciences,
Dr. Lee has continued the development of the University of
Minnesota program in the control area. He was the advisor
of 3 Ph.D. students and 4 M.S. students who completed their
work during 1971. His own research has concentrated on the
development of techniques for control systems synthesis.

Publications

1) Krzysztof Burhardt, "Urban traffic system optimization," Ph.D. Thesis, University of Minn. 1971.

2) Donald Gustafson, "Parameter estimation in systems described by differential delay equations" Ph.D. Thesis, University of Minnesota 1971.

3) H. Koivo, "Fredholm resolvents in the optimization of linear systems with state and control retardations," Ph.D. thesis, University of Minnesota 1971.

4) Yogish Alekal, Pavol Brunovsky, Dong Chyung, and E. Bruce Lee, "The quadratic problem for systems with time delays." IEEE Transactions on Automatic Control, Vol. AC 16, No. 6, Dec. 1971.

5) H. Koivo, "On the equivalence of maximum principle open loop controllers and Caratheodory type feedback controllers for time delay systems." to appear.

6) H. Koivo and E.B. Lee, "Feedback controller synthesis for systems with control delay" IFAC Symp.-Control of Distributed Systems, Banff, Canada 1971. (To appear also in Automatica, March 1972.)

7) D. Spyker and E.B. Lee, "On linear periodic control problems," IEEE Transactions on Auto Control 1972.

8) Roberto Triggiani, "Controllability of linear systems in Banach space with bounded operations." Princeton systems theory conference paper 1972.